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Guide for Type of Measurement, Choice of Location and Type of Instruments for Underground Power House

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FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Hydraulic Structures Instrumentation Sectional Committee had been approved by the Water Resources Division Council.

This Indian standard deals with the type of measurements recommended in underground caverns specifically power house of river valley projects. To overcome the problem of scarcity of space and to accommodate strategically important structures use of underground space for the purpose of construction of power house in river valley projects is increasing day by day. Excavation of earth changes natural state of equilibrium around the excavated zone and creates instability of rock mass locally. To establish the state of equilibrium support system is designed and erected. Rock/soil being the natural material its response to changed stress regime is not easy to predict. Incomplete knowledge of complex earth environment and design of structure on simple assumption like homogeneous and isotropic earth are the main factors which make the role of instrumentation crucial. Instrumentations provide quantitative measurement of parameters which are helpful in assessing behavior of rock mass during the entire life span of Structure.

Role of instrumentation is essential in all three stages of a project that is, pre-construction, during construction and post construction phase. The objective of instrumentation is different during these three stages of project. During pre-construction stage instrumentation provides quantitative measure of physical parameters required for designing of structure. During construction it helps in controlling design parameters and to assess the adequacy of support system and requirement of additional support. Any deviation from predicted behavior (behavior of rock mass observed through instrumentation) also gives indication for improvement for designing of structures in future. Under construction stage, instrumentation also helps to settle legal issues arising due to construction activities of underground openings. Role of instrumentation during post construction fulfills safety aspects and indicates any instability taking place well in advance thereby giving time to take remedial measures, before any failure to take place.

Planning instrumentation programme for underground power house is a crucial issue which requires technical as well as administrative support. Planning instrumentation poses very fundamental questions, which needs to be understood by a designer very well. As what is to be measured, where is to be measured, which type of instrument is to be selected. At the same time finalization of specification of instruments should also be done judiciously. Since, over specification may increase the cost of instruments whereas under specification may not serve the purpose of instrumentation. Robust and good quality instruments of long term reliability should be selected for installation since replacement of instruments at later stage would not be possible. Successful instrumentation programme is achieved only if every step in planning and execution is taken judiciously. Availability and installation of instruments in pace with construction activity also a necessity of successful instrumentation programme. Planning and implementation of instrumentation programme requires the association of designer of structure, geotechnical experts and construction engineers responsible for construction activities. Preservation of instruments during construction activity should be done on top priority basis.

In this code an effort is made to indicate the type of measurement generally recommended in underground openings. Suitable instruments for these measurements in different environment have been suggested. Purpose of different measurements has also been discussed.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 1960 ‘Rules for rounding off numerical values (*revised*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

GUIDE FOR TYPE OF MEASUREMENT, CHOICE OF LOCATION AND TYPE OF INSTRUMENTS FOR UNDERGROUND POWER HOUSE

1 SCOPE

This standard indicates the types of measurements need to be done in underground openings specifically in power house of river valley projects. Type of measurements to be done has been recommended and its role in assessing the stability of structure has also been discussed. Criteria of choice and location of measuring instrument are also indicated.

2 REFERENCES

The following Indian Standards contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
13946 : 1994	Determination of rock stress — Code of practice
Part 1	Using hydraulic fracturing technique
Part 2	Using USBM type drill hole deformation gauge
Part 3	Using a CSIR or CSIRO type cell with 9 or 12 strain gauges
Part 4	Using flat jack technique
7436 (Part 2) : 1997	Guide for types of measurement for structures in river valley projects and criteria for choice and location of measuring instruments
4967 : 1968	Recommendations for seismic instrumentation for river valley projects

3 TYPE OF MEASUREMENT

3.1 Measurement of Displacement

It is the most important measurement done in underground openings. Virgin state of stress gets disturbed whenever excavation is done. Readjustment of stress in the vicinity of excavation manifests in form of displacement of rock strata. This displacement is an indication of strain developed due to excavation (change of stress field). Based on the nature of in situ stress at a location convergence movement (movement inside the cavity) or divergence movement (movement outside the cavity) is observed after excavation. Since in most of the cases component of vertical stress is more than horizontal stress, displacement towards inside the cavity (convergence) is expected. In case component of horizontal stress is more due to high tectonic stress than the vertical stress then divergence movement of walls of cavity is expected. Magnitude and rate of displacement observed at certain location is an indication of elastic or non-elastic behavior of rock mass. Displacement measurements should be done on long term basis after construction of opening also. So that measurement of time dependent deformations may also be done.

Displacement measurement can be done by using instruments given in **3.2** and **3.3**.

3.2 Multipoint Borehole Extensometer

Multipoint borehole extensometer (MPBX) is the most efficient and reliable instrument for measurement of displacements. Displacement of rock strata at different depth can be measured by use of this instrument. This instrument is installed in a borehole of suitable diameter. In hard rock, expansion cell or groutable type anchor may be selected for installation, but in case rock is fractured, groutable type anchors should be selected. Anchors are fixed at different depth and through connecting rods and attached with head of instrument which is fixed at the mouth of borehole. End of these rods may be connected with sensors to observe the data remotely or displacement may be measured with the help of micrometer if location of instrument is accessible. A number of anchors may be fixed at different depth (limited to size of borehole) to observe displacement taking place from different depth. Generally three point MPBX are used in view to keep a compromise between borehole size (diameter of borehole) and number of depth point which are required for measurement. Deepest anchor should be fixed preferably in undisturbed zone. If the location of instrument is accessible during the monitoring period, a mechanical instrument shall suffice the purpose. A remotely observed instrument should be selected if location of instrument is not accessible during the monitoring period. On the basis of working principal or type of sensors attached with anchors, MPBX are classified as hydraulic, pneumatic, electrical/ electronics, optical and fibre optics based. There are no sensors attached with connecting rods in case of mechanical MPBX. Observed displacement is measured by using micrometer. Location of mechanical MPBX should be accessible during monitoring period.

3.3 Tape Extensometer

This is the simplest and most economical instrument for measurement of displacement in underground openings. Displacement measurement is done by fixing grouted studs on opposite walls of cavity or on walls and crown of cavity. The studs may be fixed to suitable depth. Distance between two studs measured by tape extensometer to assess the convergence or divergence of walls of cavity with time. This method has following limitation:

a) Relative movement between the two locations on opposite wall is known but exact movement of any wall in isolation may not be ascertained.
b) Depth of origin point of displacement or depth of discontinuity which is cause of movement may not be known by this method.
c) During the observation of data (distance measurement by tape extensometer) vehicle or manpower movement is stopped.
d) Location of studs should be accessible during observation period.
e) Regular calibration of tape extensometer is very important during the period of measurements. Systematic errors in measurements are avoided by regular calibration of instruments.
f) There is a limitation to accuracy and resolution achieved during observation since it is a mechanical instrument.

3.4 Geodetic Measurement

This is a fast method of observation of displacement of walls of underground cavities. Geodetic Targets of suitable type like reflexive targets, bi-reflexive are installed permanently on the walls and crown of cavity. Targets are fixed on groutable anchors fixed at suitable depth. The targets may be fixed on convergence bolt in case of mounting on shotcrete or on steel support system. Measurement of distance/ angle by using electronic distance measuring device / theodolite /total station system, from fixed location gives indication of movement of wall of cavity. Various advanced techniques like LASER, LIDAR and radar interferometry are also in use for taking convergence measurements in underground openings. Accuracy of convergence measurement under this category depends on employed techniques, characteristic of reference datum and measuring point. Advantage of these advance survey techniques is the capability of automatic and continuous monitoring. This also enables to set warning levels.

Like measurements done by tape extensometers depth of origin point of displacement may not be known by this method also. Advantage of this method is that during measurement no movement of vehicles or persons is affected and there is no need to access the location of the targets.

3.5 Measurement of Joint Spacing at the Surface of Excavation

Movement across the cracks developed at the excavated surface, or joints/fissures exposed at the surface of excavation may be measured by using surface joint meter (non embedded type). Embedded type joint meters are used in concrete gravity dams. Mechanical type or remote (electrical or v-w type) type joint meters may be installed to monitor movement across the joint. These are also called convergence meters by some manufacturers. Joint meters (tri axial) capable of measuring displacements in three orthogonal directions should be preferred to measure nature of movement completely. Displacement across the joint at excavated surface is an indication of movement taking place along the joints at depth.

3.6 Instrumented Rock Bolts

These are used to observe longitudinal strain of rock bolts due to load exerted by rock mass. Rock bolt with inbuilt strain meters are installed for this purpose. Strain observed is an indication of acting load on rock mass. Acting load may also be used to calculate longitudinal displacement of rock mass within elastic limit of rock mass.

4 MEASUREMENT OF PORE PRESSURE

Pore pressure at suitable depth below the wall of cavity may be measured by installation of piezometer at required depth in a borehole of suitable diameter. Measurement of pore pressure by installation of piezometer in dam is done to assess the effectiveness of drainage system. Whereas, measurement of pore pressure beneath the wall of cavities is done to know the state of effective stress around the excavation. Since increase of pore pressure reduces the effective stress and thereby increases the chances of shear failure of rock mass. Piezometers are used for measurement of pore pressure at required depth beneath the surface of underground cavities. Piezometers are available in different forms which are to be used in different environment and based on working principle namely, hydraulic piezometers, twin tube piezometers, open stand pipe piezometers, electrical resistance piezometers, push in piezometers and V-w type piezometers. Stand pipe Piezometers also known as Casagrande piezometers, are used to measure pore pressure in vertical holes. Twin tube piezometers also called pneumatic piezometers, are used to measure pore water pressure in saturated soil. Push in piezometer is used to monitor pressure of shallow ground water and soil vapours. In underground openings mostly below the ground level, electric piezometers and v-w type piezometers are used to measure pore pressure in rock mass. Electric piezometers and v-w type piezometers are useful since measurement may be taken from remote location. Multiple piezometers may be installed in a single hole at different depth for observation of pore pressure at respective depth.

4.1 Measurement of Rock Temperature

Measurement of rock temperature is essential in underground openings in case of shear zones and hot water zones. Measurement of temperature helps in understanding the state of thermal stress of rock mass. High rock temperature is an indication of active tectonic forces in the area. Increase in temperature causes rock mass to expand and thereby increases compressive stress in rock mass. Measurement of temperature is also important to make temperature correction in the response of transducers which are sensitive to temperature and used for measurement of other parameters. Measurement of rock temperature is also essential to ensure the effective working of manpower and machines and to provide effective ventilation system during construction phase of underground cavities. Measurement of rock temperature is done by remotely monitored temperature meter. Temperature meters based on resistance, vibrating wire and fiber optics principle may be used for measurement of rock temperature.

4.2 Measurement of Stress

Stress at a point in rock mass depends on weight of overlying material, geological structures, tectonic forces and residual and thermal stress present there. Due to this complex nature estimation of in situ stress in rock at a point and its spatial variation is not possible. Measurement of in situ stress is an important parameter for design and construction of underground opening (underground power house). Knowledge of in situ stress before excavation is essential for design of underground power house. The shape, size, orientation, layout and design of support system are to be decided on the basis of4 magnitude and direction of principal components of stress. Detailed information on various methods of in situ stress measurements are available in IS 13946 (Part 1, Part 2, Part 3 and Part 4). These stress measurement techniques are for measurement of absolute stress at a location. Repeated use of any technique at certain location gives the change in stress.

5 MEASUREMENT OF SEISMICITY

Seismicity of project area should be monitored by installation of micro-seismic networks as per IS 4967 in case of underground power house also as it is recommended in case of a large concrete and masonry dam. Though there is no requirement of installation of strong motion accelerographs in case of underground power house.

6 MEASUREMENTS TO BE DONE ON SUPPORT SYSTEM OF UNDERGROUND OPENINGS

6.1 Measurement of Load on Support System

Load cells are used for measurement of load on support system that is rock bolts, cable anchors and tendons, and structural members like ribs. Monitoring of load cell gives change in load on cable anchor/rock bolt etc. after installation of load cell. A decrease in load on rock bolt / cable anchor indicates anchor failure or failure of anchorage whereas an excessive increase is an indication to take remedial action. Load cell suitable for measurement of tensile load are provided with a central hole to accommodate anchor bolt / cable anchor. Whereas, to monitor compressive load the load cell is provided with inbuilt solid centre plate mounted on end faces of load sensing elements. A load cell consists of 3 or 6 load sensing elements should be preferred since, it is capable of measuring eccentric load. An average of sensing elements gives the applied load. Load cell data is useful for correlation with the data of multipoint borehole extensometer if installed adjacent to load cell. Various type of load cells based on operating principals and suitable in different environment are available that is, strain gauge load cell, piezoelectric load cell, hydraulic load cell, pneumatic load cell, geomechanical load cells and v-w type load cells.

6.2 Measurement of Strain in Support System

Measurement of strain developed in support system is done to know the state of developed stress in ribs, steel liners, pressure shafts and wye sections etc. Unless strain values are converted to stress it carries no relevance. The strain gauges are directly attached to the surface of structure or are embedded within the structure for measurement of strain. As in dams strain gages are embedded in concrete to monitor the development of strain in blocks. Generally strain meters are installed on the surface of steel support system in underground openings. Embedded type strain gages are used in concrete lining of underground openings for measurement of strain. Most commonly used mechanical strain gauge is a portable gauge with dial indicators suitable for surface mounting. At some places curvometers designed to monitor the change in curvature of a straight and curved beam at a given point have also been used. For the purpose of remote monitoring or the place where surface of support would be covered, surface mounted electrical resistance strain gauges or vibrating wire type strain meters are used. Surface mounted strain meters are available as bonded or weldable type.

6.3 Measurement of Stress in Shotcrete

Shotcrete stress cells are designed to measure radial and tangential stress in shotcrete lining in underground openings. Shotcrete stress cell provides the significant data for assessment of required thickness and stability of shotcrete lining in NATM (New Austrian Tunneling Methods). Stress cells are used to observe the change in stress taking place after installation of cell. Stress cells are sensitive to temperature change. Temperature compensation factor should be applied in each measurement. Shotcrete stress cell based on resistance and v-w technology are available in market generally.

6.4 Measurement of Stress in Concrete Lining

In the similar way stress developed in concrete lining if provided in underground opening may be measured by using concrete stress cells which are similar to shotcrete stress cells. Dimensions of Concrete stress cell may differ from shotcrete stress cell though principal of measurement is same in both the cases. Measurement of tensile stress is not possible by use of concrete stress cells.

6.5 Measurement of Earth Pressure

Earth pressure at the face of structural elements is measured by embedded or contact earth pressure cell. Earth pressure cells are seldom used in underground cavities specifically in underground power house.

7 CRITERIA SELECTION OF LOCATION OF INSTALLATION OF INSTRUMENTS

There is no simple rule which can determine the number of instruments, type of instrument and location where instruments should be installed. Selection of instruments should be done on the basis of required measurement which meaningfully defined the rock response. Though selection of remote versus mechanical instruments is decided on the fact that whether location of instrument would be accessible during monitoring or not. During construction both mechanical and remote instrument may be installed with a view that mechanical instruments would be monitored till the location is accessible. Though remote instruments shall serve the purpose during operation phase of project also. Selection of location of instruments should be decided by designer of cavity in consultation with geotechnical expert. In general instruments should be installed in weak zones like shear or fault zones, zones of expected high stress concentration; hot water zones etc. zones of high water ingress and at junction of cavities. F.E.M. analysis also indicates location of weak zones / high stress concentration to be encountered during excavation. Generally instruments are installed in sections in underground openings. In one section instruments are installed at location like centre line of crown, spring lines and suitable locations on both walls of cavity. Convergence measurement on these locations and measurement of load (on rock bolts) on these locations should be done. Pore pressure measurement on these locations at suitable depth should be done. Additionally, piezometers should be installed in zones of high water ingress. It is recommended that 2-3 sections should selected in 50 meter long cavity. Instruments to monitor some specific response parameter may be decided by the designer of structure. For cavities of longer lengths number of sections should be increased proportionately depending on geological conditions. Keeping in view the low survival rate of instruments and very high cost of replacement of instruments at a later stage, it is always beneficial to install some extra instruments.

8 GENERAL CHARACTERISTICS OF INSTRUMENTS

Selected instruments should have characteristics as given in **6.1.8** of IS 7436 (Part 2).

9 DATA TO BE PRESERVED

Following data should be preserved for interpretation of instrumentation data and for repair and maintenance work of instruments in due course of time:

a) Excavation sequence of underground opening;

b) Details of major support system installed in underground opening;

c) Installation reports of instruments comprising type of instrument, location of instrument, initial data of instrument, colour codes of wires attached to different sensors, test reports and calibration curves of instruments etc;

d) Data of drill holes (loggings) prepared before or during construction;

e) Test results of laboratory testing of rock samples;

f) Data of failure occurred during or after construction; and

g) Details of drainage holes.

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